

THE ACCURACY OF ULTRASONIC THICKNESS MEASUREMENT OF DISTORTED GRAIN STRUCTURE METAL SAMPLES*

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Abstract: Thickness measurement is one of the commonly used control measurements in sheet metal forming. Ultrasonic thickness measurement systems demand access to the material only from one side which makes them very useful for this purpose. Distortion of grain structure of the workpiece influences ultrasonic velocity and in that way directly influences ultrasonic thickness measurement. Three different ultrasonic thickness measurement systems are examined on the same working sample. Two systems are defined by standard EN14127. The third system is not defined by the standard and includes previously measured ultrasonic velocity in specific direction of grain elongation. Statistical analysis shows relations between measurement results obtained by all three systems and highlights the third system as the most accurate one.

Key Words: Grain elongation, ultrasonic thickness measurement, ultrasonic velocity

1. INTRODUCTION

Metal forming is group of processes in which products are processed without material removal, the action of compressive forces causes plastic deformation and changes the initial shape of material. Metal forming processes are classified as either hot forming or cold forming considering the working temperatures. Cold forming processes are maintained below the recrystallization temperatures, in most cases at room temperatures.

During any metal forming process the subjected material undergoes work hardening and the microstructure is being deformed following the contours of the workpiece surface, as shown in Figure 1. This phenomenon is very expressed in cold working processed, and existing, but less expressed, in hot working. Considering the microstructure, the grains and inclusions distort in direction of processing, resulting in anisotropic engineering properties [1]. In metal forming processes anisotropy is the property which implies different properties in different directions [1-3]. Anisotropy is successfully removed by annealing process.

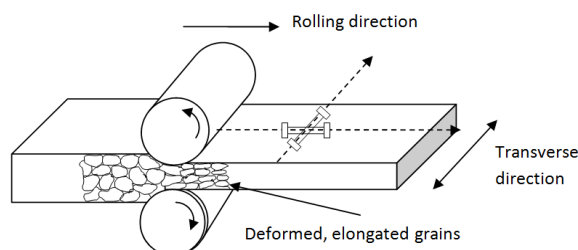


Figure 1. Grain distortion and elongation in forming direction (cold formed workpiece)

In roll forming process of metal sheets one of the prime conditions of successful production is a uniform thickness along sheet width (Figure 1). Because of

that, as a part of a quality control and assurance in industry, it is usual to measure sheet thickness during the rolling process, just after the sheet passes through the pair of rollers. This means that in the measuring moment the sheet did not pass any heat treatment, and its grain structure is still elongated and deformed. In [3] is described the influence of grain distortion on ultrasonic velocity in specific material. Greater ultrasonic velocity is measured in the plane normal to forming direction. In the direction parallel to elongated grain structure exist larger number of grain boundaries and ultrasonic velocity decreases. Because of described influence, it is legitimate to assume that elongated structure can influence the accuracy of ultrasonic thickness measurement.

The goal of this work is to quantify the influence of ultrasonic measurement system adjustment on the ultrasound thickness measurement results. The measurement is performed on 3 different setup modes of ultrasonic measurement systems for measuring the same cold formed sample with distorted grain structure. The sample was extruded (cold worked) cylindrical profile. Because of the similar behaviour of metal flow under activity of tensile stress, the structure of sample material is equivalent to rolled plate or any other cold worked part. The two types of ultrasound setting of measurement system are often performed, while the third one requires a more complex approach on ultrasonic measuring system calibration.

The usage of ultrasound in material characterization started in the middle of 20th century. It was dedicated to provide a good diagnosis of material properties and process control in industrial application. The problem of wave propagation in cubic and hexagonal structured materials was usually investigated with purpose to measure the ultrasonic velocity [4].

Ultrasonic thickness measurement is a widely used non-destructive testing technique for measuring the

thickness of a sample, where is sufficient access from one side of sample. The thickness of sample is commonly determinate by means of ultrasonic pulse reflection from the boundaries between materials with different acoustic impedance. Described method is known as pulse-echo technique. The principle of ultrasonic pulse-echo technique is divided in 4 modes in accordance to standard EN 14127 [5].

Except of the thickness measurement importance, it is well known that ultrasonic velocity is very important parameter of ultrasound setting of measurement system.

The setting of ultrasonic measurement system could be performed in two ways. It could be set by means of known ultrasonic velocity in materials or by means of known dimension of the calibration block. This paper presents 3 different measurement systems, where each of them had different approach on measuring system calibration.

2. ULTRASONIC VELOCITY

Ultrasonic velocity is an important acoustic parameter in material characterization, because it correlates to elastic parameter, structural inhomogeneities, precipitates, dislocations, phase transformations, porosity and cracks, vacancies, concentrations of different components of alloys, electrical resistivity, specific heat, thermal conductivity, etc. It is also very important because different mechanical properties like tensile strength, yield strength, hardness and fracture toughness can be determined by the measurement of ultrasonic velocity. All listed datas are useful for quality control and assurance in material producing industries.

Nowadays numerous researches are occupied with processing of the ultrasonic pulses [6, 7]. The goal is to the determinate the ultrasonic velocity. Ultrasonic impulses are mechanical and elastic vibration of particles in the material. The shape of impulses depends on microstructure and mechanical properties of material. Ultrasonic velocity also depends on the density of material, elastic properties, the temperature of material and internal stresses. In case when the thickness of the material is known, ultrasonic velocity can be determined by using a digital oscilloscope.

Many authors have discussed the problems of measuring ultrasonic velocity in different materials. The experiments have showed that the microstructure reflects the differences in propagation speed of the ultrasonic pulses. It means that different materials will also have different propagation speed of the ultrasonic pulses.

One experiment with two types of steel was done to show that the change of ultrasonic velocity depends on the microstructure [8]. The difference between the steels was different heat treatment provided and different attainable microstructures. Velocity of longitudinal and transverse waves was measured for each sample. The results have shown that the change of ultrasonic velocity depends on the microstructure and material hardness. The difference in velocity

between the samples was caused by different microstructures that affected on the elastic properties of materials. The ultrasonic velocity in material also depends on degree of deformation, the grain orientation, etc. Several other authors dealt with propagation of ultrasonic waves in various materials and structures [9-16]. Numerous researches in the field of ultrasonic waves and material characterization have shown that there is still a great potential for progress in this scientific area.

3. COMPARISON OF ULTRASONIC THICKNESS MEASUREMENTS

Measurements are conducted on the one specimen with tested and investigated structure. The specimen is cold extruded aluminium profile with distorted elongated microstructure. Figure 2 shows the specimen and its microstructure.

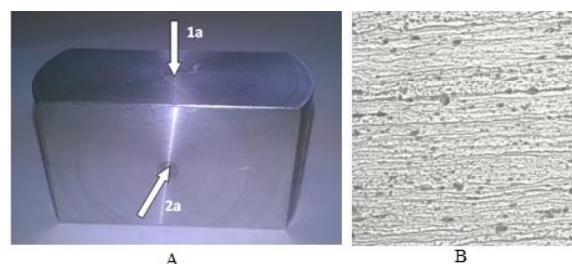


Figure 2. Aluminium specimen (A) and its microstructure in the place 2a (B)

The sample is prepared out of full 50 mm cylindrical profile, 25 mm high, which is plane parallel cut on two sides so that cut thickness is 25 mm. Before cutting the sample suffered 25 % reduction because of deformation process. The most equable grain shape remains in the area of the axis of symmetry. Because of that the sample are prepared that only this area can be observed.

Measurements of material thickness were examined on 3 different ultrasonic measuring systems wherein each of them is differently adjusted. With each of 3 measuring systems there were performed measurements in two directions on experimental sample: in direction 1a and direction 2a. The main difference between two directions is in grain elongation which follows forming force activity. In specific case grain structure is elongated in direction parallel with 2a surface (Figure 2, Figure 3).

Case 1

The first measurement system is consisted of digital ultrasonic device intended for ultrasonic testing. This equipment can be used for ultrasonic thickness measurement, according to standard EN14127 [5]. Used ultrasonic probe was Top Coat probe (TC-560). This probe can measure the ultrasonic velocity of the sample and is able to adjust the ultrasonic velocity on the fly. The probe also records the thickness measurements while the velocity is being measured.

Case 2.

The second measurement system consists of the instruments designed primarily for discontinuity detection. This ultrasonic equipment can be used for ultrasonic measurement of thickness according to standard EN 14127. The measurement was performed with MB5S probe which is commonly used for thickness measurement. Calibration was performed by means of known dimensions of calibration block. The calibration block was made from the same material as sample that will be measured with isotropic microstructure.

Case 3.

The third measurement system consists also of the instruments designed primarily for discontinuity detection. The measurement was performed with G5KB probe. This kind of probe can be used in referenced research [3] for the measurement of the ultrasonic velocity, according to the standard EN 14127, considering the measurement of ultrasonic velocity in undetermined materials. Mean value of measured velocities differs in correlation with measuring direction. For the examined sample it is 6466.88 m/s in 1a direction and 6430.98 m/s in 2a direction as shown in Figure 3. Adjustment of measurement system was performed by listed means of known ultrasonic velocity for every direction of grain distortion, specified in stated research [3].

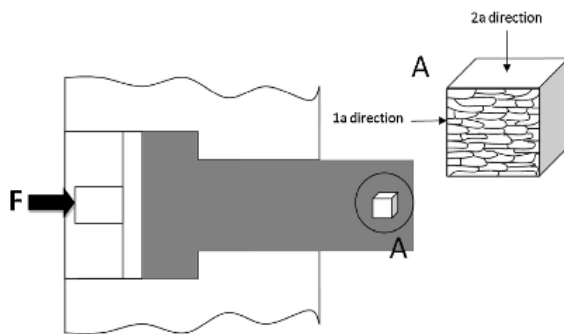


Figure 3. Detail A of tested aluminium part [3]

4. STATISTICAL ANALYSIS OF MEASUREMENT RESULTS FOR THREE DIFFERENT MEASURING SYSTEMS

Statistical analysis of measurement results for thicknesses in places 1a and 2a measured with use of different ultrasonic probes is conducted. All measurements are repeated five times. Analysis of variance on results of both measuring directions is carried out and p -values are determined to be less than alpha risk which is 5 %. This means that there is a significant difference between the arithmetic means of the measurement results obtained with use of different ultrasonic probes.

Results of ANOVA analysis for measurements in place 1a and 2a are given in Table 1 and Table 2.

Table 1. ANOVA results for 1a

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	p-Value
Factor	2	0.165173	0.082587	1032.33	0.000
Error	12	0.000960	0.000080		
Total	14	0.166133			

Table 2. ANOVA results for 2a

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	p-Value
Factor	2	0.202720	0.101360	460.73	0.000
Error	12	0.002640	0.000220		
Total	14	0.205360			

Measurement results of measurement thickness at places 1a and 2a are presented in Figure 4 and Figure 5 respectively in Figure 6 and Figure 7.

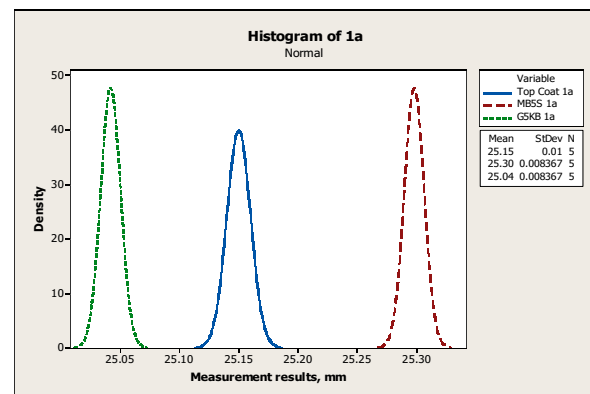


Figure 4. Histogram of thickness measurements on place 1a

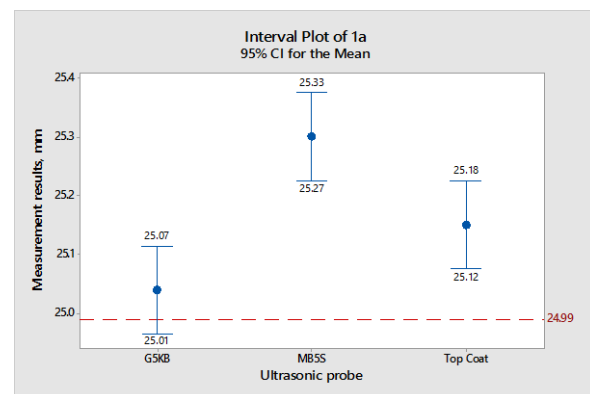


Figure 5. Graphical overview of measurement results on place 1a

Figure 5 and Figure 7 show measured results at place 1a, respectively 2a in dependence of reference value. Reference measurements for both thicknesses 1a and 2a were conducted on length device and are equal to 24,99 mm for place 1a and 24,97 mm for place 2a. Both reference results are given with extended measurement uncertainty $U = 4 \mu\text{m}$, coverage factor $k = 2$ and probability $P=95 \%$.

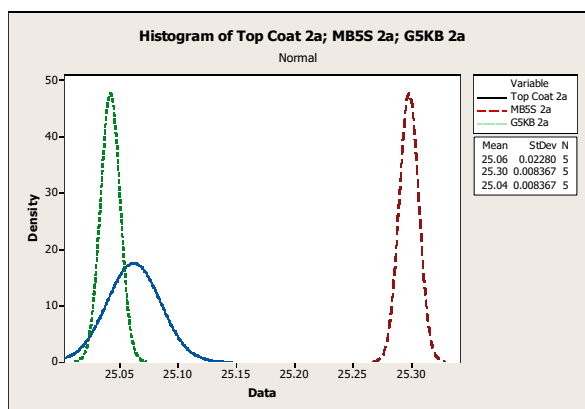


Figure 6. Histogram of thickness measurements on place 2a

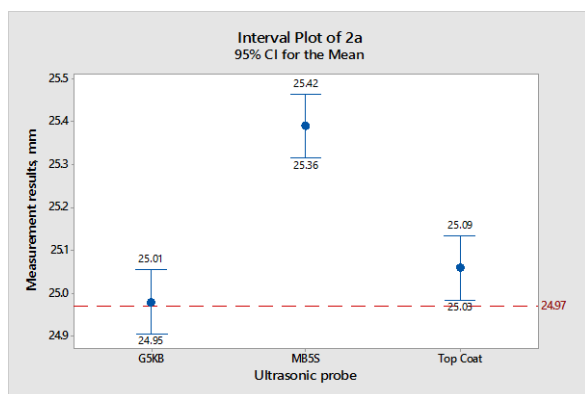


Figure 7. Graphical overview of measurement results on place 2a

Interpretation:

Figure 6 shows the significant difference between measurement results obtained with probe G5KB and probe MB5S, and also between measurement results obtained with probe Top Coat and probe MB5S. In order to determine statistical difference between results obtained with Top Coat and G5KB probes, an additional analysis is conducted. Results, given in Table 3, shows no significant difference between analyzed results ($p = 0.103$).

Table 3. ANOVA for Top Coat and G5KB – 2a

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	p-Value
Factor	1	0.001000	0.001000	3.39	0.103
Error	8	0.002360	0.000295		
Total	9	0.003360			

5. CONCLUSION

Thickness measurements of cold extruded aluminium sample were performed by three different ultrasonic measurement systems. Two of them are defined by standard EN 14127. The third one is based on previously measured ultrasonic velocity which is determined to be dependent on the orientation of grain elongation direction.

From the statistical analysis of obtained measurement results it can be concluded that the

minor deviation from the reference value is accomplished, when ultrasonic measurement system is set according to primarily known ultrasonic velocity in each direction.

The deviation is medium in the system with its own ultrasonic velocity settings.

The major deviations shows the system, where the ultrasonic velocity is set on isotropic materials on the standard sample made of homogenous material with identical chemical composition and the data are used for anisotropic materials. It is important to notice that, according to standard, reference samples must have isotropic microstructure.

Furthermore, from everything stated is obvious that for improvement of ultrasonic thickness measurement in industry, in case of anisotropic materials, it is vital to be familiar with ultrasonic velocity value in different directions of grain distortion.

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